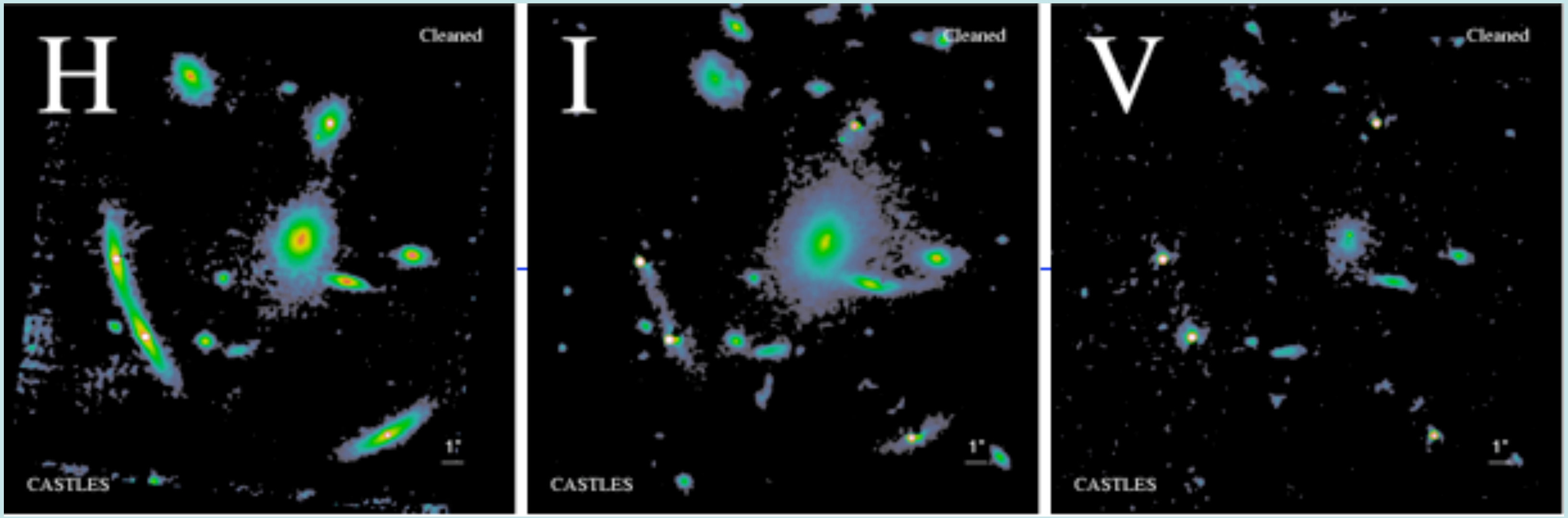
Lensing statistics in large low redshift surveys



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Talk Outline

- Overview of surveys past and present
- Constraints from survey data, limitations
- The lens-redshift test
  - constraints on cosmological parameters ?
  - constraints on galaxy evolution?
- Arm chair surveys: simulating a 2dF lensing survey in the Millenium Run
- Future prospects

SURVEY STRATEGIES

- Search among source population for lensed cases
- Search behind potential lenses for lensed sources
- Optical and radio wavelengths

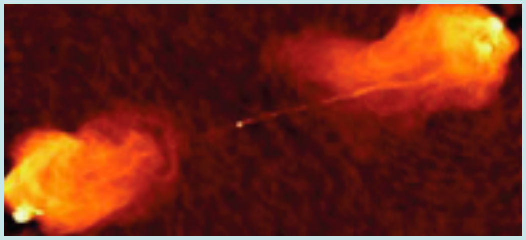
↓

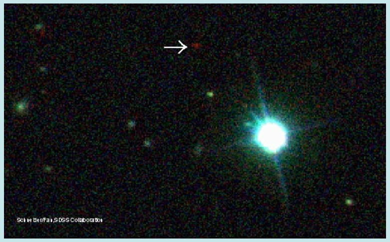
CONSTRAINTS ON COSMOLOGY
CONSTRAINTS ON GALAXY EVOLUTION

LENSING STATISTICS

SOURCE IMAGE PROPERTIES

source lensed fraction, separation distribution, quads/doubles, arc length/width, flux ratios





galaxies radio-galaxies quasars

LENS PROPERTIES

redshift, mass/density profile

Lensing probability

Probability = n σ D

Lens number density

Distance to source

Lensing cross section

Galaxies 0.5×10^{-2} Mpc^{-3} x π (5 kpc)^2 x 2 Gpc ~ 10^{-3}

X mag. bias ~ 10 (bright quasars)

~ few (radio galaxies)

Optical depth to lensing

$$\tau(z_S, \Omega_m, \Omega_\Lambda) = \frac{1}{4\pi} \int_0^{z_S} dV \int_0^\infty d\sigma \;\phi(\sigma; z_L)\; A(\sigma, \Omega_m, \Omega_\Lambda, z_L, z_S) B(S_\nu)$$

z_s - source redshift

z_l - lens redshift

A - the cross section for multiple imaging

B - magnification bias

With the optical depth known, the distribution of image separations and lens redshift distribution can be derived and used to get constraints on cosmology &/ galaxy evolution

Turner, Ostriker & Gott '84; Turner '90; Fukugita & Turner '91
Kochanek '93; Kochanek '96; Mitchell et al. '05; Chae '05, '06

SURVEYS

HST Snapshot lensing survey (Maoz et al. ‘93)

4/502 ~ 1% of luminous quasars are lensed

$\Omega_\Lambda < 0.7$ (95% C.L.)

Kochanek (1996): SIS + 5/864 lensed quasars

$\Omega_\Lambda < 0.66$ (95% C.L.)

Chiba & Yoshii ‘97 ‘99

$\Omega_\Lambda \sim 0.8$, $\Omega_\Lambda = 0.7 \pm 0.1$

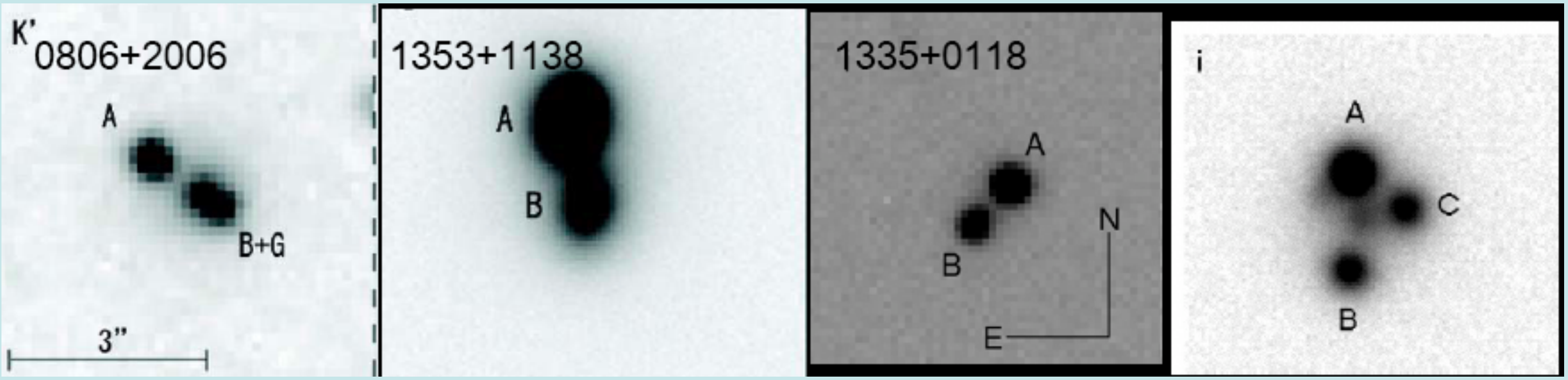
Waga & Micelli ‘99

$\Omega_\Lambda < 0.67$

HST Snapshot lensing survey II (Morgan et al ‘03)

3/320 ~1% of luminous quasars lensed

SDSS quasar lens search (Pindor et al. '03; Inada et al. '06; Oguri et al. '06) ~ 20 new lenses



Lensed QSOs from the SDSS spectroscopic QSO sample (I <19) 0.6 < z < 2.2, Extended QSOs at < 1.5", like-color companion at separation > 1.5"

SDSS lensed QSOs at z > 3 HST snapshot imaging of high-z QSOs (Richards et al. '04) Lensed fraction = 0/154 Provides limit on steepness of the high-z QSO LF

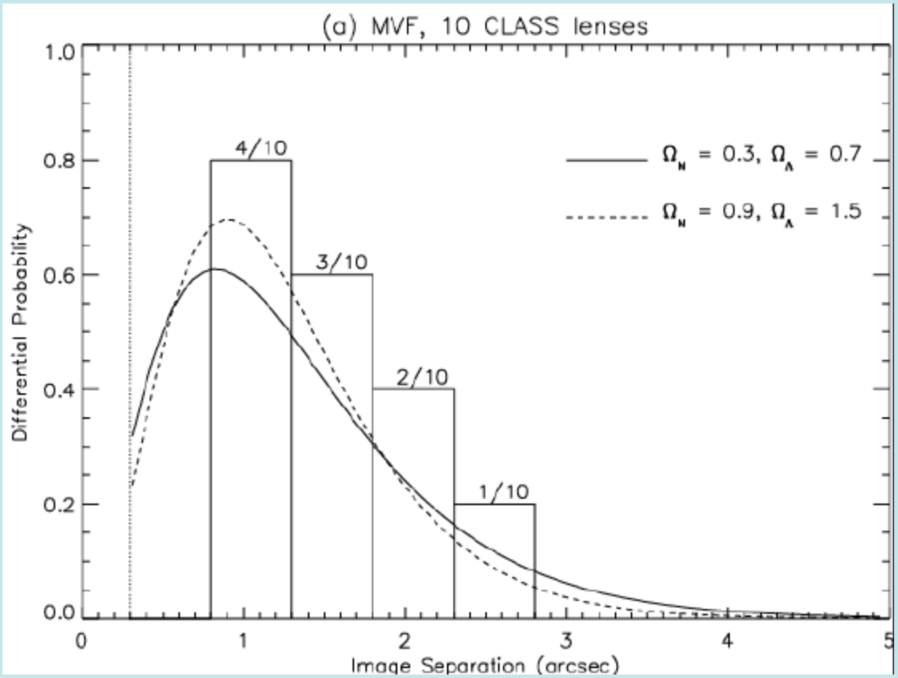
Variable extended sources = lensed sources (Kochanek et al. '06)

Surveys of radio sources

JVAS/CLASS (Browne et al. '03; Myers et al. '03)
+ no extinction, large uniform samples
- source population redshift and LF poorly known
Falco, Kochanek & Munoz '98
6/2500 JVAS sources lensed

Chae '03
13/9000 CLASS sources lensed
Ω_Λ=0.8±0.05

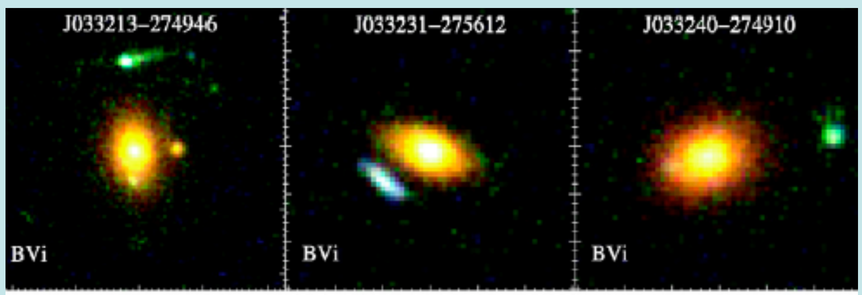
Mitchell et al. '05
10-12/9000 CLASS sources lensed
Ω_Λ=0.75±0.05



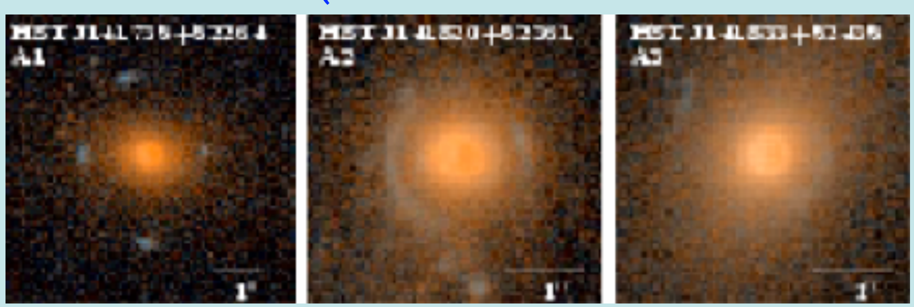
SDSS-HST surveys

SLACS (Bolton et al. ‘06; Willis et al. ‘05 ‘06)

HST-GOODS (Fassnacht et al. ‘04)



HST-AEGIS (Moustakas et al. ‘06)



THE LENS-REDSHIFT TEST

$$\frac{d\tau}{dzdr} = \tau_\star{}' \frac{\beta'}{2\Gamma(\alpha'/\beta')} \left(\frac{r}{r'_\star} \frac{1}{f_E{}^2} \frac{D_S}{D_{LS}} \right)^{\frac{\alpha'}{2}}$$
$$\times \exp\left[- \left(\frac{r}{r'_\star} \frac{1}{f_E{}^2} \frac{D_S}{D_{LS}} \right)^{\frac{\beta'}{2}} 10^{-\beta' U' z} \right]$$
$$\times \frac{D_L{}^2 (1+z)^2}{r_H{}^2 E(z)} \frac{r}{r'^2_\star} 10^{[\alpha' - U' + P']z}.$$

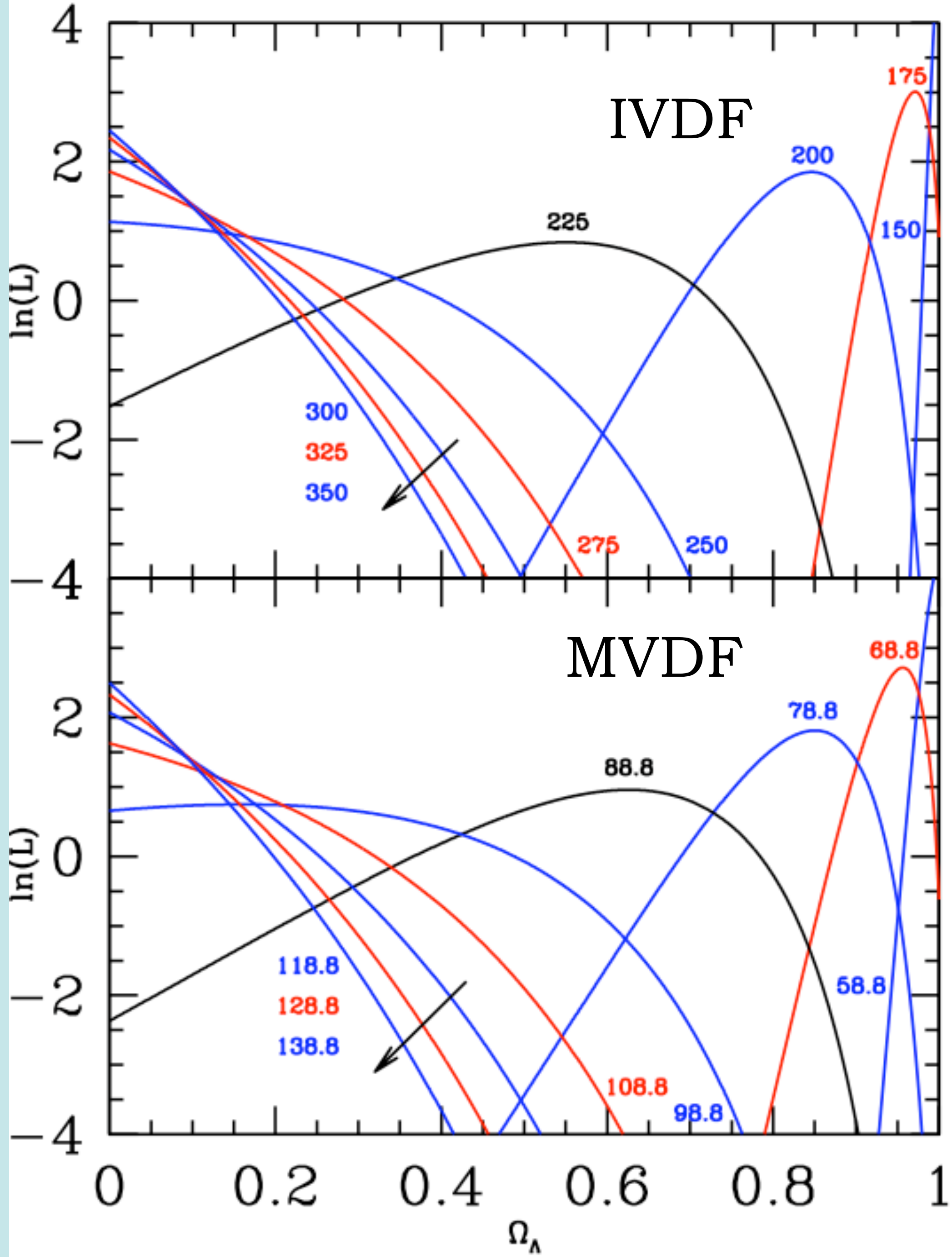
$$n_\star(z) = n_\star 10^{Pz},$$
$$L_\star(z) = L_\star 10^{Qz},$$
$$\sigma_\star(z) = \sigma_\star 10^{Uz},$$

r - angular critical radius

U’, P’ - parameters describing galaxy evolution

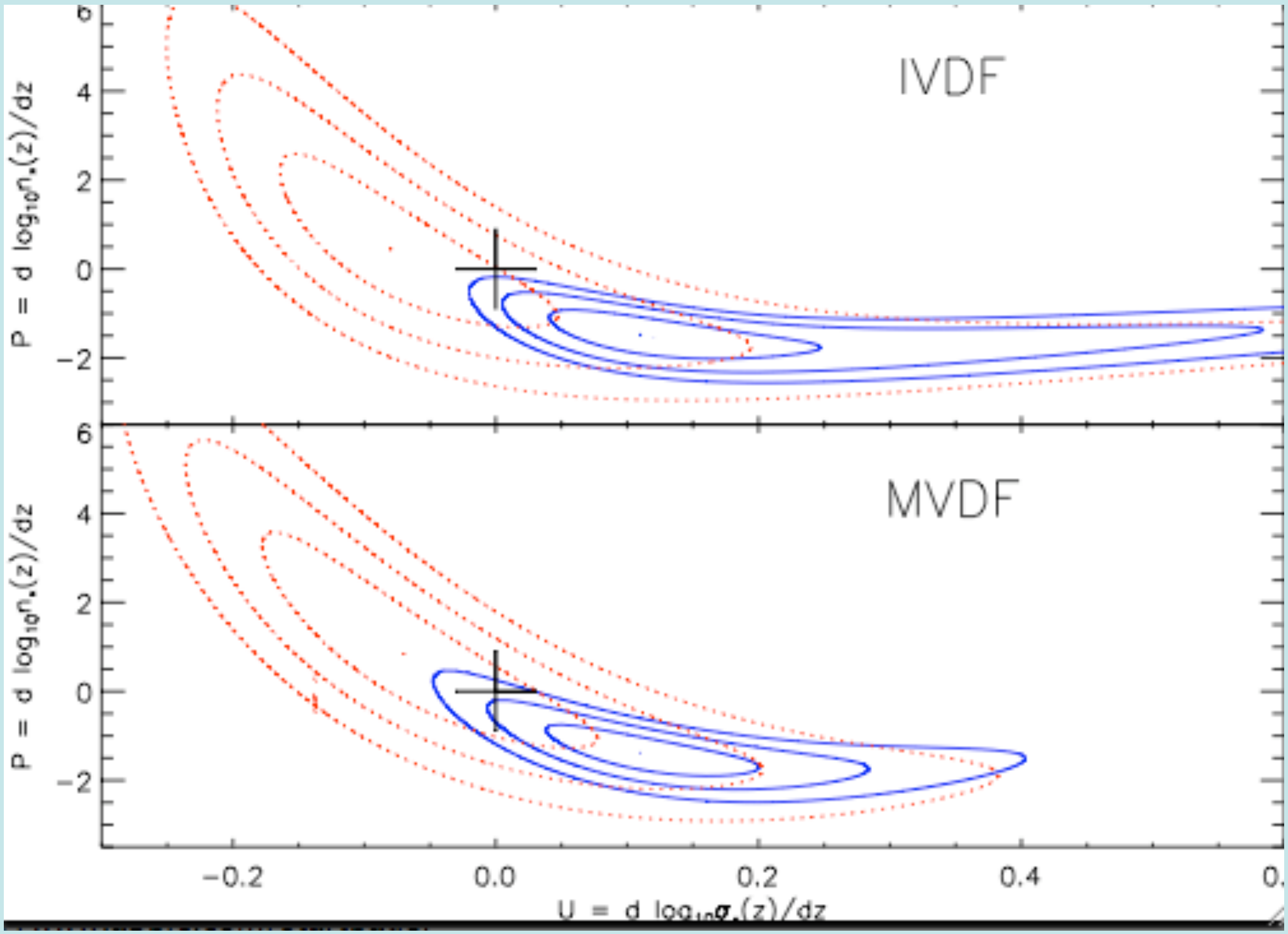
Can use the above to constrain cosmology or evolution parameters, done for 42 lens systems

Kochanek ‘96; Ofek et al. ‘05; Capelo & Natarajan ‘07

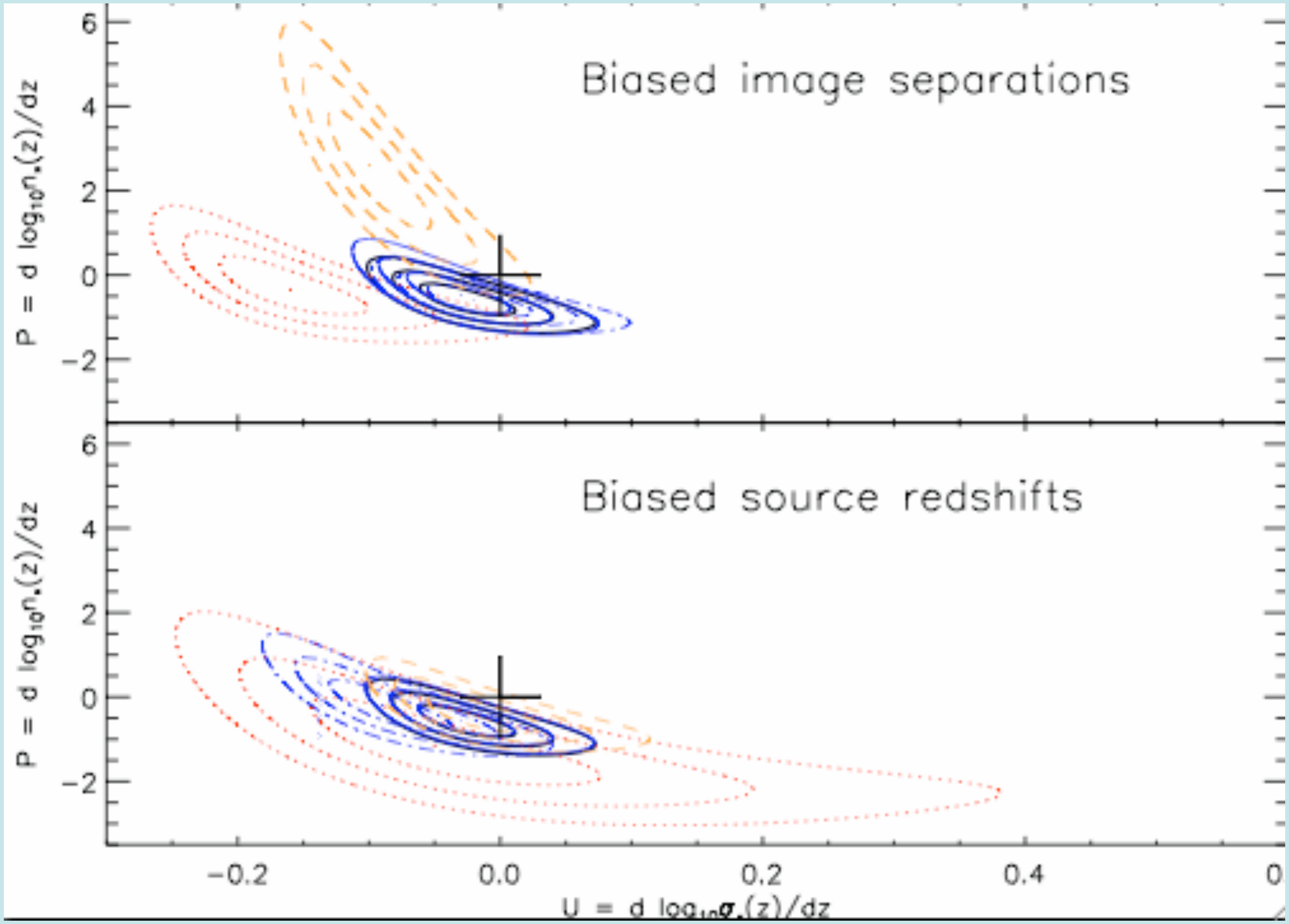


Very sensitive to the velocity dispersion function, weakly constrains Ω_Λ

Biased recovery of U & P



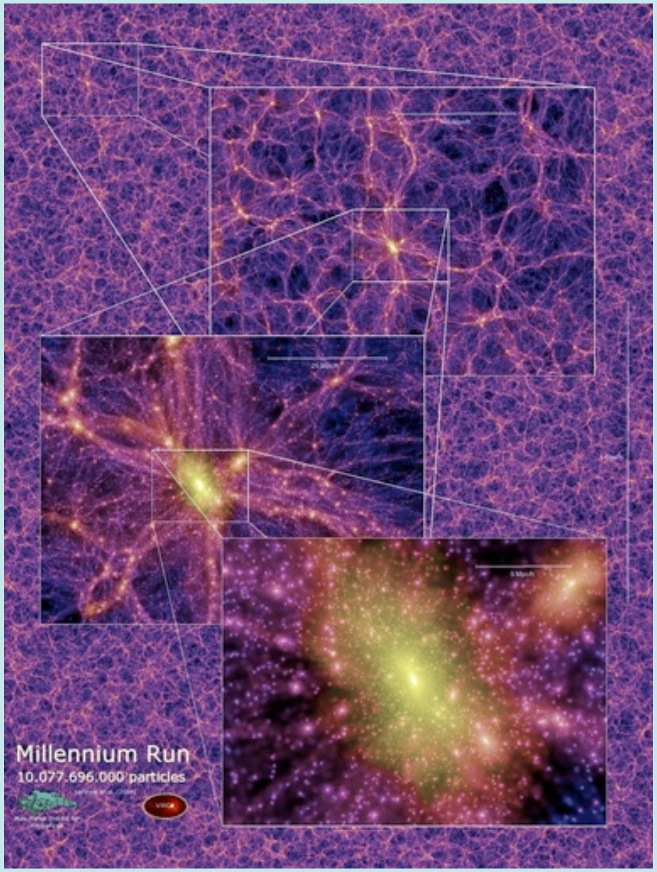
What are the causes of these biases?



Investigate with mock catalogs, biased separation distribution, biased source redshifts, incomplete information

A LENS SURVEY THRU THE MILLENIUM SIMULATION

With known cosmological parameters calculate expected lensing statistics of a galaxy population for a large, low z survey



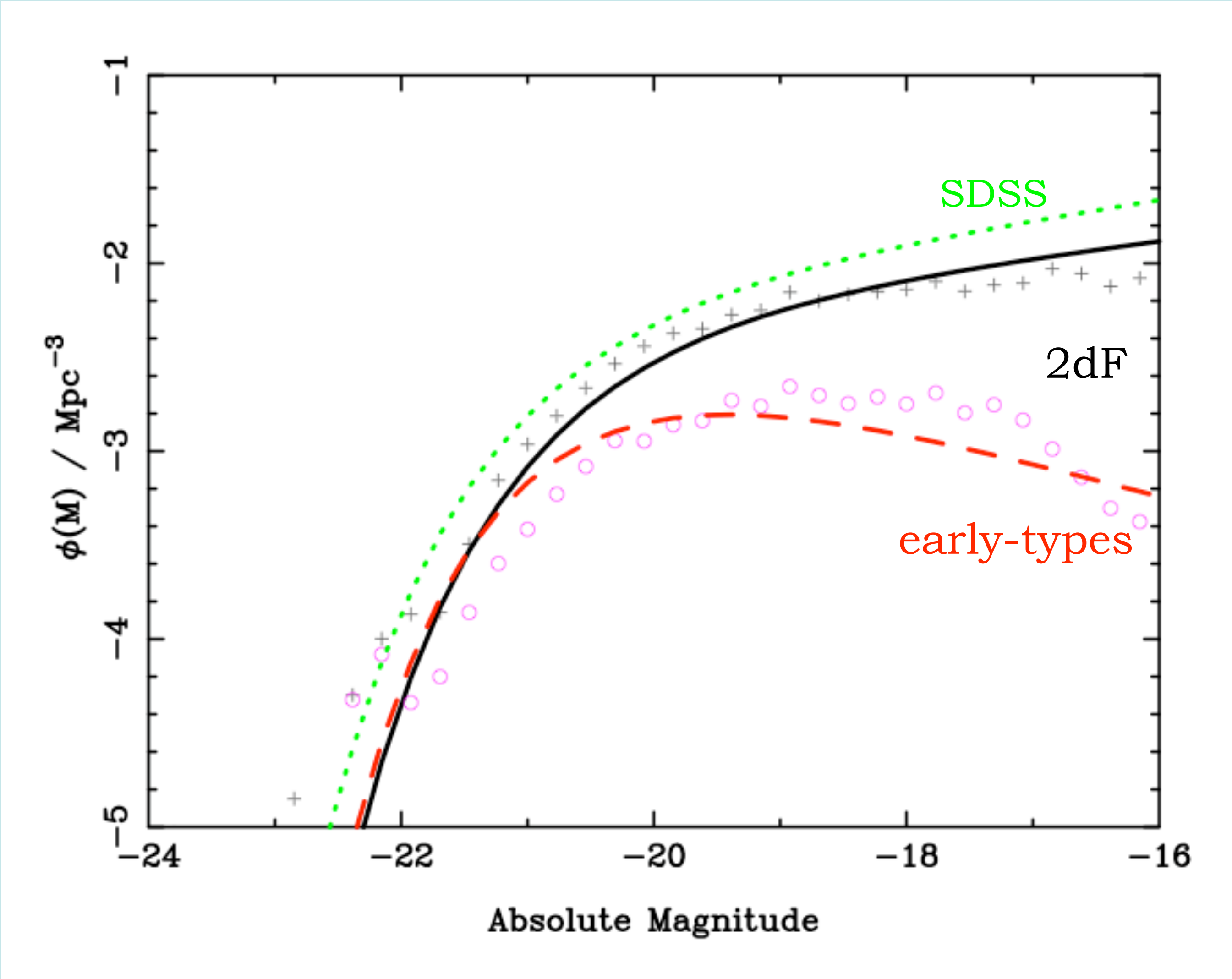
Predictions for the selection criteria of 2dF

Moeller, Kitzbilcher & PN ‘07

Modeling lens galaxies

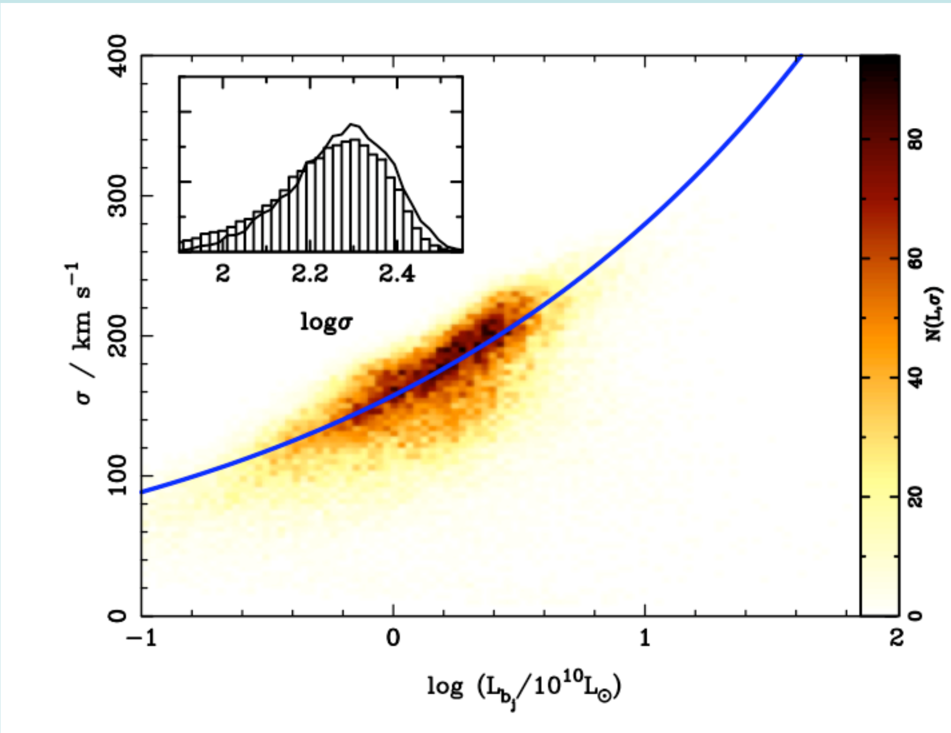
- Dark matter - NFW profile for halos, V_{vir}, V_{max} from simulations => c, and scatter in c
- Baryonic component - bulge + disk from SAMs, bulge and disk stellar mass => L_{bul}, L_{disk},(Croton et al. '06) morphology B/T > 0.4 (early-type), rest late-type (Allen et al. '06; de Jong '96)
- Bulge - de Vauc profile, allow for ellipticity, all galaxies have disks [76% of all galaxies late-type]
- Sizes assigned using SDSS (Bernardi et al. '03) relation: $R_{1/2}$ - L
- Vel. disp calculated using Jeans eqn., recover Faber-Jackson and observed SDSS relation: σ-L
- Triaxiality not taken into account (Oguri & Keeton '04)

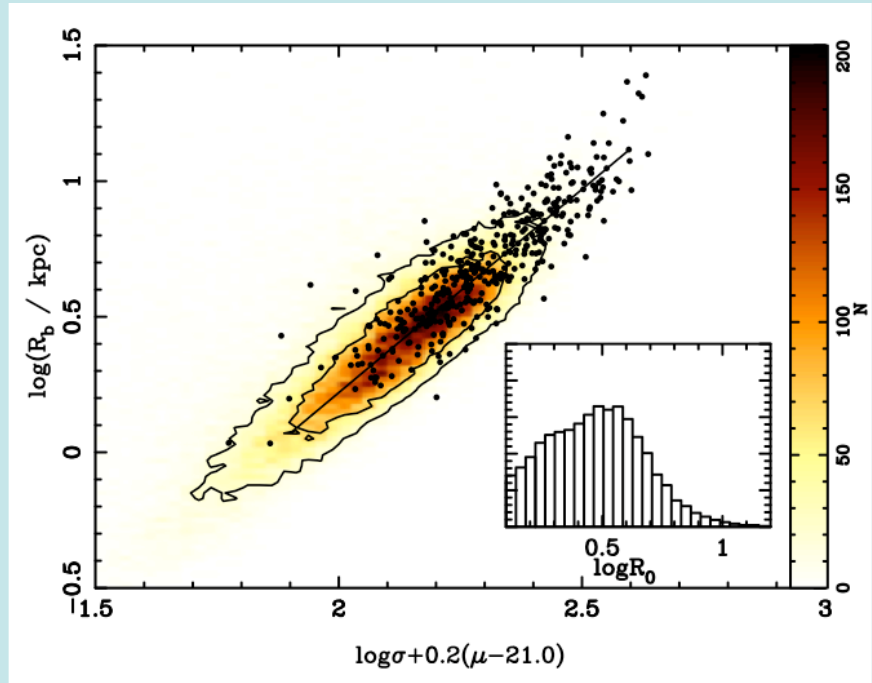
How realistic are our galaxies?



Recovery of observed properties

Early-types

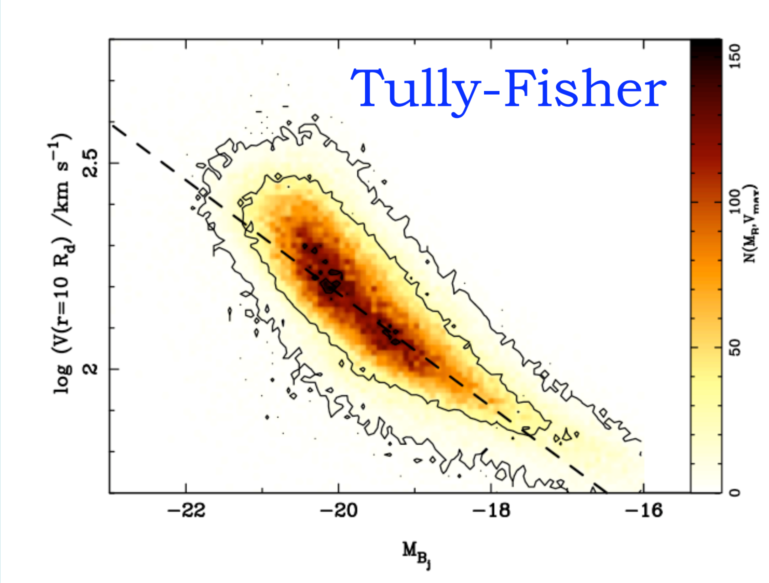


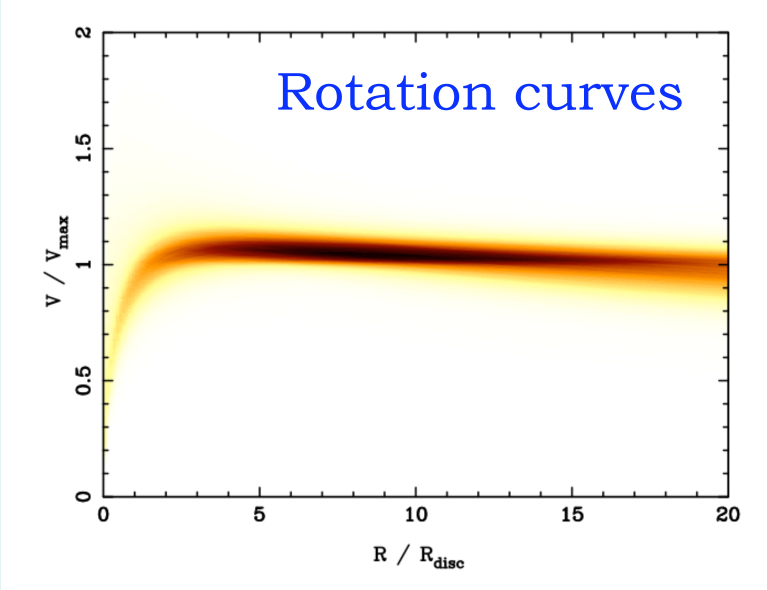


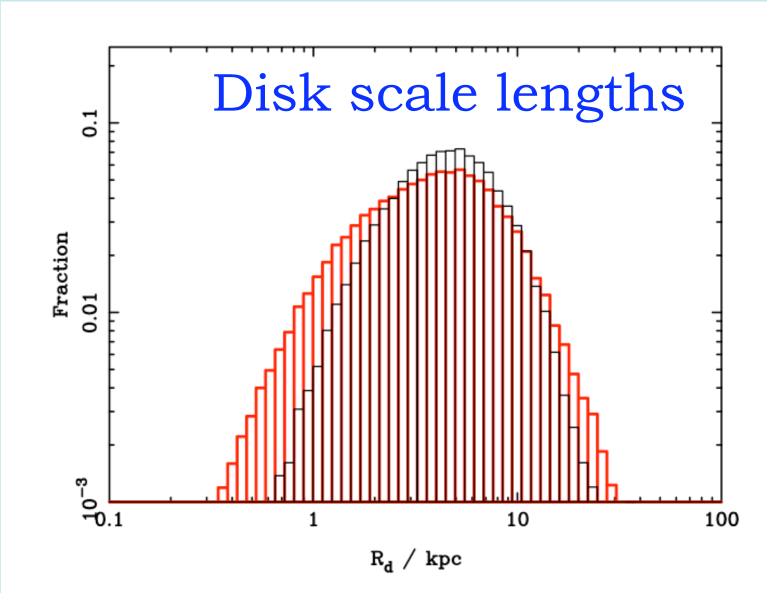
Faber-Jackson

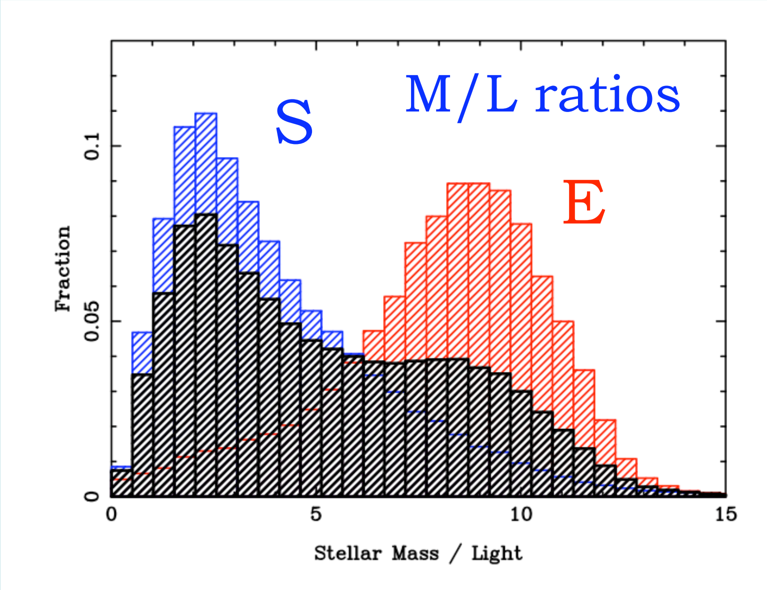
Fundamental Plane

Late-types

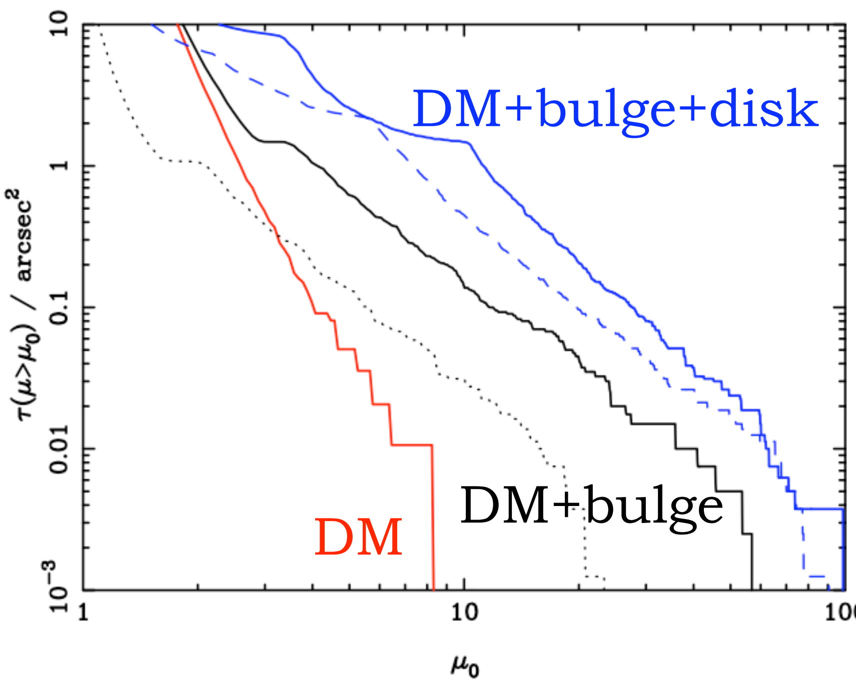

Tully-Fisher
log (V(r=10 R_d) /km s^-1)
M_Bj
N(M_B,V_max)

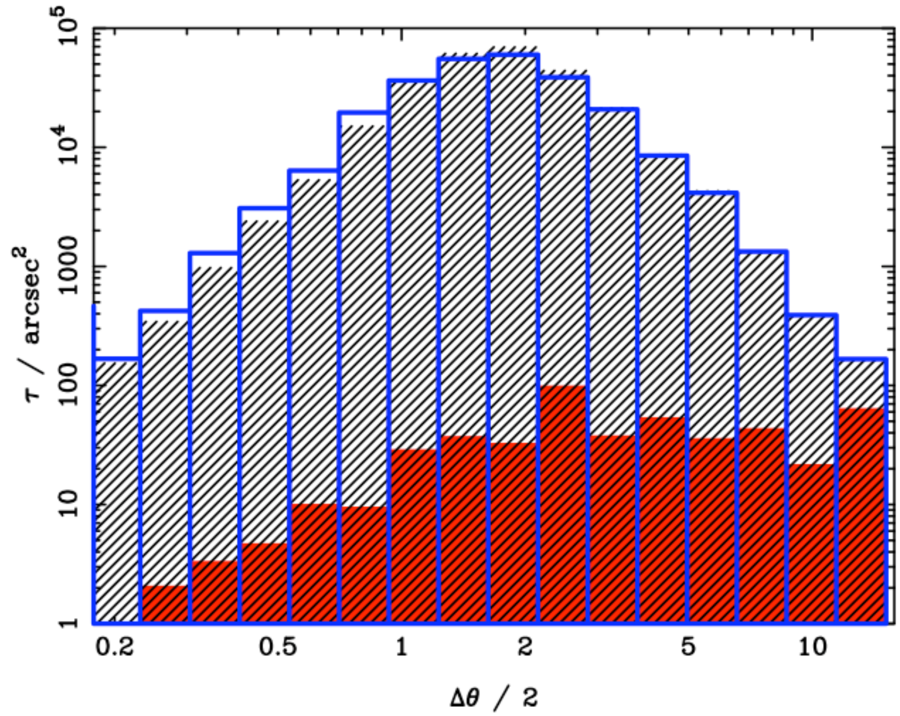

Rotation curves
V / V_max
R / R_disc


Disk scale lengths
Fraction
R_d / kpc


M/L ratios
S
E
Fraction
Stellar Mass / Light

Lensing properties of the population

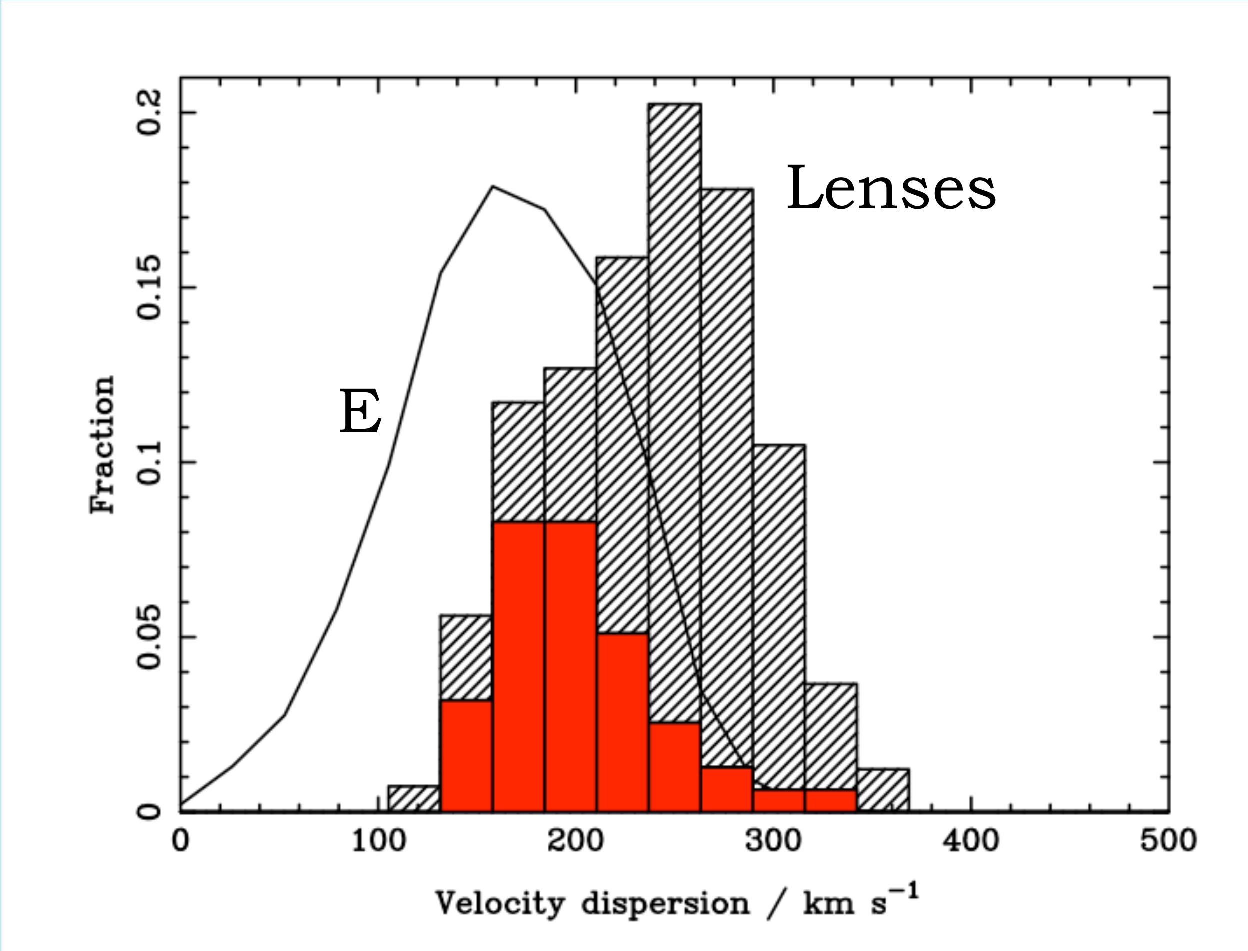




Lensing cross section

Image separation distribution

How biased are lens galaxies?



85% of all lenses early-types, 4-image lenses lower σ

Key results

- Consistent with CLASS survey fraction of 4:2 image ratio systems
- For 2dF ($z < 0.2$), fraction of lensed radio sources ~$7.5 \pm 0.2 \times 10^{-5}$
- Baryonic component crucial for accurate lensing statistics (cross-sections)
- Lenses mostly early-types (~ 85%), $\langle\sigma\rangle \sim 190$ kms^{-1} typical image sep. ~ 1.5”
- Lenses that produce 4 images tend be lower vel. disp with more disky component
- Magnification bias strongly affects ratio of 4:2 image systems

Lens galaxies are a biased population

- Lens galaxies are more luminous and for a fixed L reside in dark matter halos that have masses that are a factor of 2 higher than the overall galaxy population
- The velocity dispersion of lens galaxies is shifted to significantly higher values compared to all galaxies (~190 kms^{-1} vs. ~ 150kms^{-1})
- Four image system lenses on average lower velocity dispersion, later type morphology and lower maximum image separations compared to two image system lenses

FUTURE LENS SURVEYS

- Expect v. large lens samples from SKA, LSST, SNAP
- SKA - 20,000 sq deg. imaged to 3μJy at 0.01” resolution, 1 billion sources (starburst galaxies) ~ 10^6 lenses
- LSST -15,000 sq deg. survey
- SNAP - 10,000 sq deg. Survey
- Large samples will enable lensing to compete in the determination of cosmological parameters and galaxy evolution
- Meanwhile continue mining of SDSS, CFHT-LS, HST